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The water - energy nexus in drinking water treatment plants in West Bengal and Orissa

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ABSTRACT

The general objective of this study was to compare energy consumption and water quality parameters in various water supply systems (WSSs) in West Bengal and Orissa. Specifically, the objective was to determine the amount of energy consumed in delivering a unit of treated drinking water (measured as specific energy consumption - SEC, kWh/m^3) in various drinking water supply systems in the region. Additionally, water quality at every stage in the treatment plants was evaluated. Eight municipal water supply systems (WSSs) were covered in this survey and included Mukut Manipur, IIT Kharagpur, Uluberia and Kamal Nagar in West Bengal; Cuttack (High Level Tank), Naraj, Sambalpur and Buhasuni in Odisha. Primary and secondary energy consumption data in terms of electricity costs were collected from each treatment plant. Water samples were collected from the outlets of various treatment units and then transported to our laboratory and analyzed for various water quality parameters. Electricity costs were available from Cuttack and Bhubaneswar WSSs and were 47.6% and 39.5%, respectively of the total operational and maintenance costs of the water supply systems (WSS). Results of this survey show that in these eight WSSs, on an average 25.9 % of the total energy is consumed by raw water pumping and 66.2% is consumed in treated water distribution pumping. An average of 5.5% of the total energy consumption is consumed in the treatment of surface water sources. The average specific energy consumption (SEC) value for these WSSs in the two states was 0.3 kWh/m^3 and varied between 0.173 to 0.397 kWh/m^3. Based on tariff rates ranging from Rs. 1.89/kWh to Rs.

5.6/kWh, total energy costs for treated drinking water in these eight WSSs were found to range between Rs. 0.63/m^3 to Rs. 2.14/m^3 with an average cost of Rs. 1.54/m^3.

Keywords: specific energy consumption, electricity costs, water quality

1. INTRODUCTION

Water and Energy are two of the most important resources in the world today. Energy is consumed at every stage in drinking water treatment and supply systems, starting from raw water intakes to service reservoirs and distribution systems. Electricity costs are a significant portion of any Urban Local Body's annual budget and in water supply systems (WSSs), these costs are associated mainly with pumping and treating water, and to a smaller extent to estate lighting and maintenance.

Conventional water treatment includes a series of processes such as screening, aeration, rapid mixing (coagulation), flocculation, clarification through settling, filtration and disinfection with the objective of removing microorganisms and contaminants of public health concern from raw water sources. The general objective of this study was to evaluate and compare the performance of various drinking water treatment plants in West Bengal and Orissa. Performance indicators measured were the amount of energy consumed in delivering a unit of treated drinking water (measured as specific energy consumption - SEC, kWh/m^3), cost of delivering a unit of treated water and whether water quality standards were satisfied in various drinking water supply systems in these states. To this end, energy consumption and water quality at every stage in the treatment plants were evaluated.

2. METHODOLOGY

Eight WTPs were selected from the Eastern India region for this survey out of which four were in West Bengal and the remaining four in Odisha. The sites were selected so that travel times from the treatment plants to Kharagpur would not exceed more than 9 hours. It was likely that sample quality would have been altered if travel times were longer. All samples collected were stored in an ice box, maintained at 4 deg C and brought to EEM Lab, Civil Engineering Department, IIT Kharagpur, West Bengal. Drinking water supply systems that were surveyed were:

1. IIT Kharagpur Water Works, Kharagpur, West Bengal
2. Mukut Manipur Water treatment plant, Mukut Manipur, West Bengal
3. High Level Tank Water Works, Bhubaneswar, Odisha
4. Bhuasuni Water Works, Bhubaneswar, Odisha
5. Naraj Water Treatment Plant, Cuttack, Odisha
6. Sambalpur Water works, Sambalpur, Odisha
7. Uluberia Water works, Uluberia, West Bengal
8. Kamal Nagar Water Treatment Plant, Kamal Nagar, West Bengal

All the selected water supply schemes use rivers as their main raw water sources and their details are summarized in Table 1.

2.1. Water Sampling Procedures and Analysis

Water samples were collected in accordance with the sampling procedures recommended in Standard methods (APHA, AWWA, & WEF, 2005). All water samples were tested for the water quality parameters listed in Table 2. For this paper, no water quality data is reported due to limitations of space. However, all water quality parameters measured satisfied both, IS and WHO standards.

2.2. Primary and Secondary Data Collection

Both primary and secondary data were collected by carrying out energy audits in selected WSSs to evaluate specific energy consumption (SEC). The rated parameters of the equipment were noted to check whether the measured parameters were in an acceptable range.

2.3. Performance Indicators

Three different performance indicators were used for evaluating and comparing WSSs performance:

1. SEC: Energy consumption per unit volume of treated water produced in kWh/m^3 was used as the major performance indicator for comparing individual unit processes, the entire water treatment plant and the WSS as a whole.

2. Cost of delivering a unit volume of treated water was also compared
3. The ability of each WSS to satisfy all drinking water standards was compared and evaluated.

Table 1. Details of Water supply systems surveyed in this study

Water Supply Scheme	IIT Kharagpur	Mukut Manipur	High Level Tank	Buhasuni	Naraj	Sambalpur Water works	Uluberia Water works	Kamal Nagar
Latitude and Longitude	22.321°N, 87.311°E	22.970°N, 86.789°E	20.268°N, 85.828°E	20.237°N, 85.840°E	20.435°N, 85.746°E	21.494°N, 83.966°E	22.453°N, 88.113°E	23.528°N, 88.362°E
R.L(in m)	50	135	59	21	42	157	4	15
Name of the source	1)Kasai river 2)Deep tube well	Mukut Manipur reservoir	1)Kuakhai river 2)Production well	Daya river	Mahanadi river	Hirakud reservoir	Hooghly river	Bhagirathi river
Type of source	1)Sub-surface water 2)Ground water	Surface water	1)Surface water 2)Ground water	Surface water	Surface water	Surface water	Surface water	Surface water
Distance of source from WTP(in m)	13000	60	6000	3500	930	15000	42	1000
Year of commissioning	2010	2005	1954	1976	1997	2003	2011	2010
Design capacity (m^3/day)	6820.5	6000	6821.3	13641	115000	40000	45470	12090
Present production (m^3/day)	4547	6000	4470	20461.5	97050	40000	24629.5	12090
Length of distribution mains(in km)	1.8	136	5.2	8.2	19.64	4.5	-	10.715
Automation	No automation	No automation	No automation	Semi automation	No automation	Semi automation	Semi automation	No automation

Table 2 List of water quality parameters tested

Parameters measured	Method/Instrument used for measurement
Temperature	Digital multiprobe
Conductivity	
TDS	
Turbidity	Digital Nephelometric Turbidimeter
pH	pH measuring electrode
Total alkalinity	Titration methods (APHA et al., 2005)
Hardness	
Flouride	Metroohm 761 Compact IC
Chloride	
Nitrite	
Bromide	
Nitrate	

Phosphate	
Sulphate	
Manganese(II)	
Ammonium	
Potassium	
HPC	Spread Plate method (APHA et al., 2005)
TOC	OI Analytical TOC analyser
Total residual chlorine	Hach colorimeteric kit

3. RESULTS AND DISCUSSION

3.1. Electricity Consumption of Water Supply Schemes

The total SEC of water supply for the WSSs studied and values for other countries are shown in Figure 1. Please note that values for other countries are ranges while those for WSSs surveyed in this study are single point values. The total SEC for the selected WSSs in West Bengal and Odisha varied from 0.173 kWh/m^3 at Kamal Nagar WSS to 0.383 kWh/m^3 at Naraj WSS.

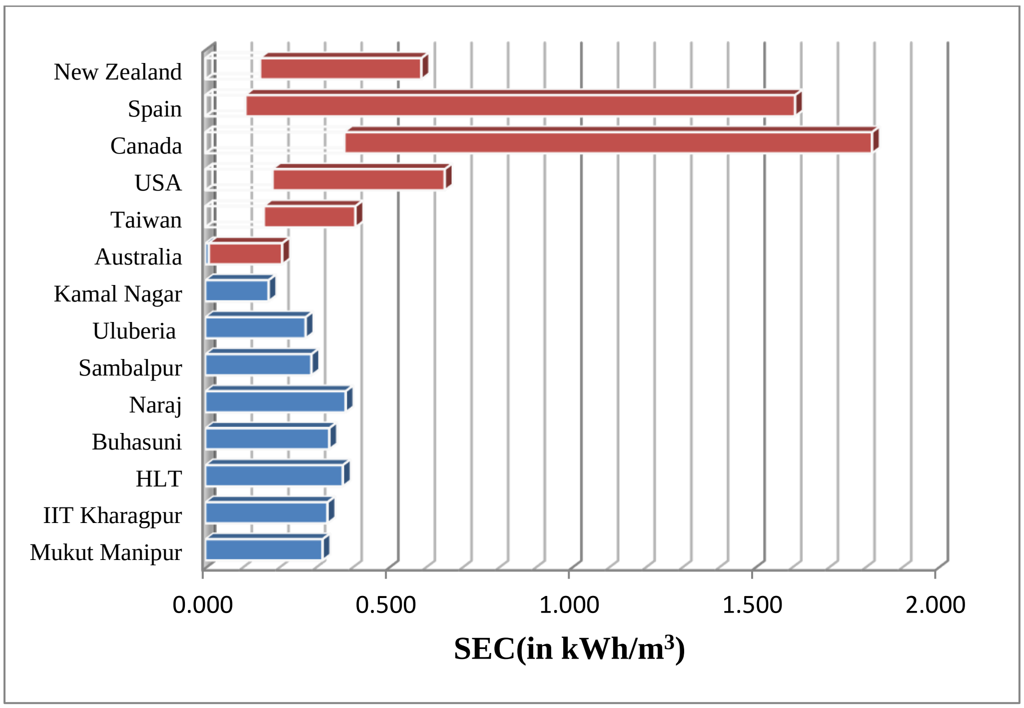

Figure 1 Comparison of SEC for different WSSs

SEC values in Figure 1 for WSSs located in these two states show that they are far less compared to those in developed countries. The reason may be adoption of energy-intensive advanced treatment processes like membrane filtration, desalination in developed countries as compared to low-energy consuming conventional treatment methods that are followed in India. Sambalpur, Uluberia and Kamal Nagar WSSs have very low SEC values. In Sambalpur WSS, no raw water pumping is required as the source of water (Hirakud reservoir) is located at a higher elevation than the treatment plant and service area. Hence energy is saved in raw water pumping. On the other hand, low SEC values were obtained for the WSSs located near the water sources in Uluberia and Kamal Nagar and have been recently commissioned, i.e., there is low head loss in pipes.

Figure 2 shows the total energy cost per m^3 of water treated for different WSSs except IIT Kharagpur as separate electricity bills for IIT Kharagpur WSS were not maintained. Table 2 shows that it is not necessary for a WSS having lower SEC to have less costs also. For example, Uluberia WSS had low SEC compared to Sambalpur, but it had higher cost due to lower tariff rates and lower demand rates in Sambalpur WSS. Also, various incentives are provided by the state governments to different WSSs which also affect their costs.

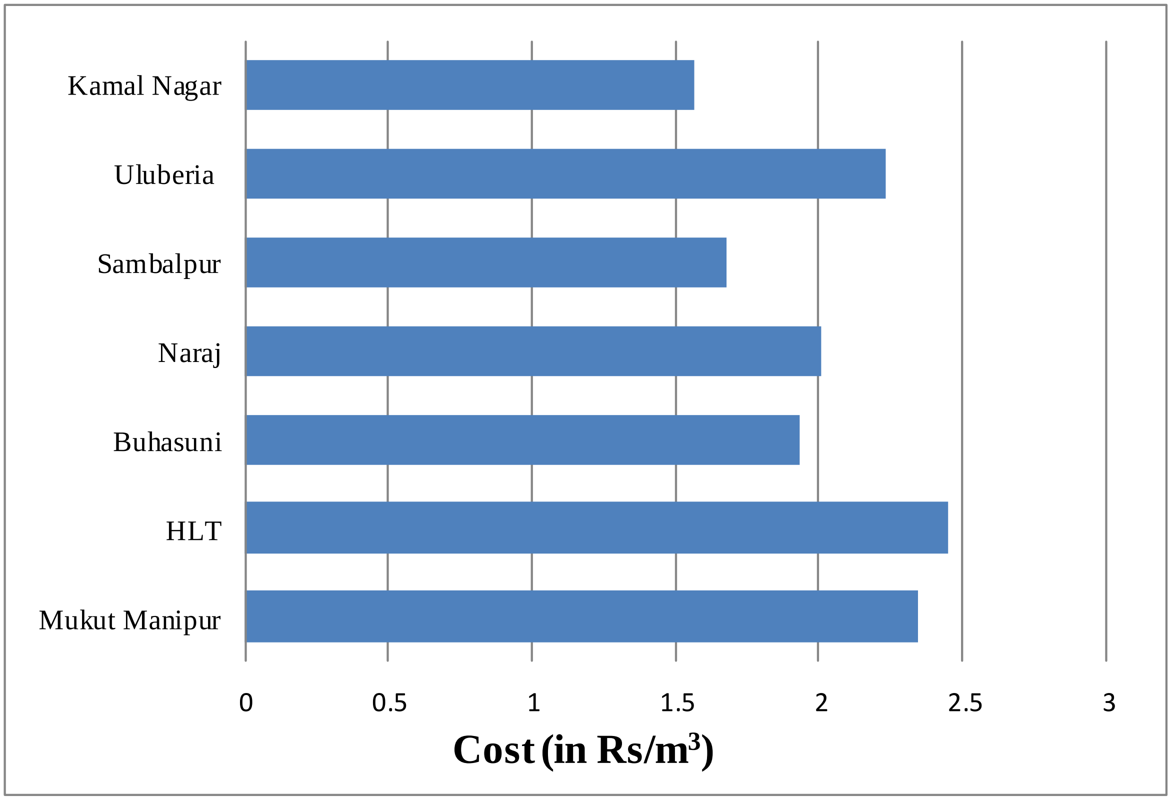

Figure 2 Comparison of total energy costs of treated water from different WSSs.

Table 3 Variation in performance indicators in different WSSs

S. No.	WSS	SEC (kWh/m^3)	Cost (Rs/m^3)	Tariff rate (Rs/kWh)	Demand rate (Rs/kVA)
1	Kamal Nagar	0.172821	1.56	5.6	317
2	Uluberia	0.273925	2.23	5.59	317
3	Sambalpur	0.289892	1.68	5.05	250
4	Mukut Manipur	0.320109	2.35	5.6	317
5	IIT Kharagpur	0.333633	-	-	-
6	Buhasuni	0.338425	1.93	5.04	-
7	HLT	0.375535	2.45	5.4	200
8	Naraj	0.383332	2.01	4.89	250

Figure 3 shows the percent variation in energy consumed by different WSSs for different uses like raw water extraction, water treatment, distribution pumping and others. Energy consumed in lightning, air-conditioning, transmission losses are included in 'others' category. Data for HLT, Bhubaneswar is not included since raw water extraction values were not available. For all WSSs

studied except Buhasuni and IIT Kharagpur, energy consumption was greatest for distribution pumping followed by raw water pumping and then treatment. For the other two WSSs, energy consumption due to raw water pumping was more than distribution pumping since water sources are located at considerable distance from the WSSs. In five of the eight WSSs surveyed, pumping accounted for more than 90% of the total energy consumption. The percentage of energy consumed in treatment was minor in comparison and varied from 1.2% to 14.2%.

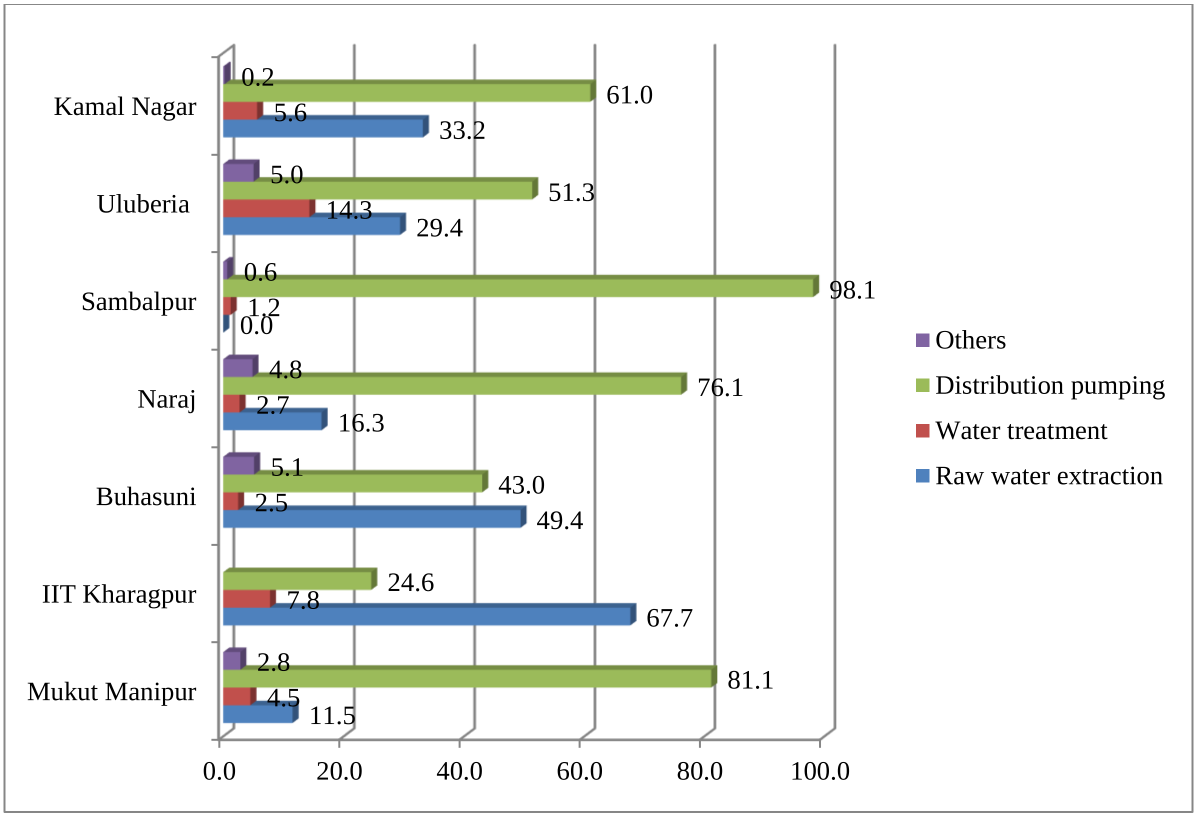

Figure 3 Percentage variation of energy consumption in WSS

Based on SEC data, it was found that SEC for raw water extraction varied from 0 at Sambalpur to 0.226 kWh/m^3 at IIT Kharagpur. SEC for treated water distribution varied from 0.082 kWh/m^3 at IIT Kharagpur to 0.374 kWh/m^3 at HLT. Low SEC at IIT Kharagpur is due to less length of distribution mains. Besides pipe length, other factors like topography, service level, pump and motor efficiencies, may vary from one treatment plant to another and also affect SEC values. SEC varied from 3.99 x 10^{-3} at Sambalpur WTP to 39.18 x 10^{-3} kWh/m^3 at Uluberia WTP. High SEC at Uluberia is due to the fact that backwash water from filtration is being recirculated while for other WSSs, it is simply discharged into wastewater pipes. Sludge dewatering is done by centrifuge process which also consumes a lot of energy.

Energy consumption of individual drinking water treatment unit processes in these WSSs are as follows:

1. Chemical feeding: (0.9 - 8.8) x 10^{-3} kWh/m^3
2. Rapid Mixing: (1.3 - 6.67) x 10^{-3} kWh/m^3
3. Slow mixing: (0.9 - 20.02) x 10^{-3} kWh/m^3
4. Filtration: (0.1 - 6.46) x 10^{-3} kWh/m^3
5. Disinfection: (2.9 - 8.06) x 10^{-3} kWh/m^3
6. Sludge treatment: (4 - 14.73) x 10^{-3} kWh/m^3

4. CONCLUSION

The following conclusions can be drawn based on this study:

- In studied WSSs, total energy costs for treated water were found to range between Rs. 1.563/m^3 to Rs. 2.451/m^3.

- Total specific energy consumption for surface water supply schemes varies from 0.173 to 0.383 kWh/m^3.
- More than 80% of the total energy consumption of WSS is consumed for raw water and distribution pumping. Energy consumption for water treatment ranges from 1.2 to 14.3 %.

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